Simple Approaches to Quantify Yield Production and Soil Responsibility to Different Water Qualities and Moisture Depletion

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Abstract: This study is an attempt to quantify the effect of different water qualities interacted with different moisture depletion levels on crop yield and leaching requirement for salt affected soil. Barley crop was cultivated on sandy soil as a pots experiment in the open field, in Ismailia, Egypt. Three water qualities were collected from different resources to represent three different water qualities: 1) Nile water, 0.4 dS m^{-1}, 2) Salam Canal, 0.8 dS m^{-1} and 3) Diluted Sea water, 7.4 dS m^{-1}. Winter barley has been irrigated with the three different waters, where each type was applied under three different levels of soil moisture depletion: 25 %, 50 % and 75 % of soil field capacity. An empirical model to predict yield production was developed and evaluated in comparison to some common models such as models of Stewart and Maas-Hoffman's models. The results showed that the suggested model could be used as reliable approach to predict the relative yield of barley cultivated in sandy soil under different water salinities and soil moisture depletion levels, as well as the leaching requirement of such salt affected soils irrigated with saline water. The validation of the common used Hoffman's equation for leaching requirements, LR, had been tested based on leaching curve experiment. The results indicated that the developed model for yield prediction may be successfully adapted to estimate the relative yield as a function of both water salinity and depletion level of soil moisture. Based on the data of leaching experiment a relative over-estimation of the LR was obtained using Hoffman's equation compared to that estimated from Oster's equation. The amounts of water applied based on Oster's equation could be reduced to about one-third of that calculated according to Hoffman and led to the provision of large amounts of water available for irrigation.

Keywords: Barley, leaching requirements, saline water, sandy soil, yield prediction

INTRODUCTION

In arid and semi-arid ecosystems, salinization is a major threat to the productivity of agricultural land. While the influence of individual physical and chemical environmental factors on soil productivity have been intensively studied in soil, the influence of interaction between water salinity and soil moisture depletion levels may be less exhaustively assessed. Many studies showed that yield decrease was related to the sensitivity of the crop to water stress (as a function of soil moisture depletion before irrigation) and to irrigation water salinity (Nuss and English, 1982; Martin and Heermann, 1984; English and Nakamura, 1989; Yuan et al., 1991; Allen et al., 1998; Zhang et al., 2009 and Hokam and Azeem, 2012).

Many attempts have been proposed to describe the effect of water stress caused by drought or by salinity on crop yield. The mostly used one is crop response factor model introduced by Stewart et al. (1977) which links the relative yield decrease with relative evapotranspiration deficit. Regarding to impacts of salinity on crop production, Letey et al. (1985) and Shalhevet (1994) concluded that effects of soil salinity and water stress are generally additive in their impacts on crop evapotranspiration. According to Stewart's model, higher yield response factor (represents the slop coefficient), the stronger the relative yield decrease at equal relative evapotranspiration deficit. In other words, more decrease in the value of the crop response factor indicates that the obtained yield will be less affected as a result of the accident reduction in water consumption under certain circumstances (Doorenbos et al., 1986 and Katerji et al., 2001). Another way to express the effect of salinity on yield could be studied by the equation of Maas and Hoffman (1977) as introduced by Ayers and Westcot (1994). The equation indicated that plant growth rate decreases linearly as soil salinity increases above a critical threshold salinity. The obtained relative yield using this equation was based on the values of soil salinity and expected yield loss per unit increase in salinity, while soil moisture depletion effect was not involved.

Some criticisms have been mentioned and may restrict the application of Stewart's model. For example, Doornenbos and Kassam (1979) reported that values of crop response factor (for the same crop) are affected and shows dispersion owing to experimental shortcoming. Stegman (1985) concluded that crop response factor could be strongly sensitive to climatic conditions where it ranged for maize from 1.25 to 1.67 with decreasing air humidity. Also crop response factor is sensitive to the leaf area index. At the same relative evapotranspiration deficit water stress and yield decrease are higher for plants with a higher leaf area index (Katerji, et al., 1991). Additionally, it was observed that crop response factor provide the effect in a quality form and not quantity, where it qualitative the response of yield to water supply and explain the sensitivity or change occurred in the relative yield responded to the lack of soil water. Therefore, these criticisms may lead to errors when crops are classified based on Stewart's equation. So, the first objective of this study was to develop a simple empirical model could be use for quantitative prediction of relative crop yield responded to water salinity interacted with soil moisture depletion.

According to Abrol et al. (1988) all irrigation waters, however "fresh", bring salts that remain behind in the soil after evaporation. For example, assuming irrigation water with a low salt concentration of 0.3 g l^{-1} (equal to 0.3 kg m^{-3} corresponding to an electric conductivity of about 0.5 dS m^{-1}) and a modest annual supply of irrigation water of 10000 m^3 ha^{-1} (almost 3 mm day^{-1}) already brings 3000 kg salt ha^{-1} each year. In the absence of sufficient natural drainage (as in waterlogged soils) and without a proper leaching and drainage program to remove salts, this would lead in the long run to a high soil salinity and reduced crop yields. There are several methods available for estimating the leaching requirements (LR) most of those are based on different perspectives on how to estimate the average root zone salinity (Hoffman, 1980; Pratt and Suarez, 1990; Ayers and Westcot, 1994; Corwin et al. 2007). Differences among methods can be significant, particularly if the root zone salinity is weighted for the amount of water uptake under high frequency irrigation and salt concentration in root zone must be defined before and is involved in most methods. As a second objective of this study was to evaluate the appropriateness of leaching requirement estimated based on Hoffman's equation as a traditional methods for leaching requirement responded to irrigation with saline water in comparison to simple approaches introduced by Oster (!994) and to clarify an advantage and disadvantage of both studied methods.

THEORIES

Crop Response Factor

The mostly used one is that introduced by Stewart et al. (1977), which links the relative yield decrease with relative evapotranspiration deficit by the following equation:

$$1 - Y_a / Y_m = K_y \left(1 - ET_a / ET_m\right) \quad 1$$

Where ET_a is the rate of actual evapotranspiration and quantified the water stress in plant, ET_m is the rate of maximum evapotranspiration. The ratio between ET_a and ET_m is named relative evapotranspiration (ET_r). In a same manner relative yield, $Y_r = Y_a / Y_m$, where Y_a is the actual yield, Y_m is the maximum yield. When full water requirements are met $Y_a = Y_m$, K_y is yield response factor, therefore, equation 1 could be written as following:

$$\left(1 - Y_r\right) = K_y \left(1 - ET_r\right) \quad 2$$

$$K_y = \left(1 - Y_r\right) / \left(1 - ET_r\right) \quad 3$$

The linearly decrease in yield occurs throughout a range of soil salinity could be obtained using the equation of Maas and Hoffman (1977) as following:

$$Y = 100 - b\left(EC_e - a\right) \quad 4$$

Where, Y = relative crop yield (percent)
ECe = salinity of soil saturation extract, dS m^{-1}.
a = salinity threshold value
b = yield loss per unit increase of salinity in excess of the threshold

Yield losses per unit increase of salinity are involved, and are given as expected values by Maas in his original paper or can be determined from equation 4. On the other hand, moisture depletion occurred in soil during growth period was not considered. This means that plant must be grown under no water shortage conditions.

Suggested Model

This investigation introduce some a specific term, such as Salinity ratio, R_s ($R_s = S_u/S_{th}$) which is the ratio between the salinity of used water, S_u, to the threshold value of salinity, S_{th}, after which the obtained yield is strongly decreased. This salinity ratio should be inversely proportional to obtained crop yield, consequently to relative yield, Y_r:

$$y_r \; 1/\propto \; R_s \quad 5$$

As found in many investigations crop yield decreases at lower soil moisture content (i.e. under high depletion level), therefore, the relative yield will be also inversely proportional to depletion level:

$$Y_r \quad 1/\propto \quad D \quad 6$$

$$Y_r \quad 1/\propto \quad R_s \; D \quad 7$$

$$Y_r = C / R_s \; D \quad 8$$

The quantity R_s D was combined together in one value, which is varied for the sam: water quality according to each depletion level (i.e. I, D_1; R_s D_2 and R_s D_3). So, it is concluded that the coı stant C (named prediction factor) will has a same value for each water quality, therefore the model could be used to predict the expected relative yield for barley irrigated with a particularly water quality.

Leaching Requirements

According to Leaching Curve technique based on equation of Hoffman (1980), the amounts of water used for leaching could be expressed as soil pore volume (P V, represented by total soil porosity, equals 40 %) based on the following relationship:

$$C / C_o = K / \left(d / d_s\right) \quad 9$$

Where, C = desirable salt concentration in soil (to which soil salinity must be reached)
C_o = salt concentration in soil before leaching
d = depth of water required for leaching
d_s = depth of soil to be leached
K = experimental constant equals to 0.1 for sandy soil. So, the depth of water required for leaching can be estimated as following:

$$d = C_o \; d_s \; K / C \quad 10$$

This technique is empirically accurate, especially at low levels of water salinity, so it is reliable, but flawed by the need for prior knowledge of final salt concentration that will exist in the soil at the end of the growing season, in addition it is time consumed.

Oster (1994) introduced a model for the case of reduced yield. In this model, the water requirement, WR, could be determined as a function of ET value for maximum yield, and water amount of leaching requirement, LR, as following:

$$WR = ET/(1 - LR) \quad 11$$

When the equation is rearranging in an adverse manner, the leaching requirement could be calculated as follows:

$$LR = 1 - ET/WR \quad 12$$

The equation shows that in the situation where the actual amount of irrigation water equaled to maximum evapotranspiration for the cultivated crop, it will not be needed for the leaching requirements. On the other side, when ET < WR, the value of LR will be positive and this means that there was overestimation for irrigation water requirement, while in the case where ET > WR, the value of LR will be negative and equals to the leaching water amount to be applied. It is clear that this model is an indirect function of stress occurred in the soil whether due to water shortage or salinity and both are represented indirectly in WR reduction.

MATERIALS AND METHODS

Experiment Layout

A pot experiment was carried out to determine the effect of different water qualities collected from different water resources (diluted Sea water, 57.8 dS m^{-1}, 1:10 to get EC of 7.4 dS m^{-1}, Salam Canal, 0.8 dS m^{-1} and Nile water, 0.4 dS m^{-1}) on yield production, salt accumulation and leaching requirements in sandy soil at the experimental Farm of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. Winter barley seeds (*Hordeum Vulgare* var. Giza 28) inoculated with two different PSB strains were sown in plastic pots (18.6 cm mean diameter and 17 cm in height) that containing a sandy soil at a rate of 5.0 kg pot^{-1} (each one contains 5 plants). Some physical and chemical properties of soil and some chemical properties of waters used in this study were presented in Table 1. In total 18 different treatments were examined. All these treatments were replicated three times, giving a total of 54 experimental units that arranged in a randomized block design. The N, P, K fertilizers were applied at the recommended levels of barley fertilization for a sandy soil.

Treatments

During the growing season, plants were subjecting to three different soil moisture depletion levels (i. e. 25 %, D_1; 50 %, D_2, and 75 %, D_3, of soil field capacity), after which different water amounts were applied. The applied water amounts were to compensate the lost water and bring soil moisture back to its field capacity. The lost water amounts were determined using a digital balance. Before planting seeds were inoculated with two different Phosphate Solubilizing Bacteria (PSB_1, named I_1 and PSB_2, named I_2). Immediately after seedling until emergence stage, each treatment was irrigated separately with Nile water, in the rate of 535 m^3 ha^{-1} (1.20 L pot^{-1}) to insure full seeds germination. After crop establishment watering of plants was daily controlled by weighting to monitoring the depletion level at which the pots must be irrigated to bring them back to soil field capacity. Volumetric soil field capacity was determined in laboratory using tension table apparatus (Klute, 1986). All different waters (i. e. Nile water, N; Salam Canal water, S, and diluted Sea water, C, 1: 10) were applied according to each depletion level. After 135 days crop was handy harvested from each pot.

Soil Leaching

To quantify the amounts of water needed for leaching salt affected soil (i.e. leaching requirements) using a simple approach, three plastic cylinders, 50 cm in height, were packed with the treated soils. Each packed soil was leached with the same water quality which used for irrigation during the season. Water amounts used for leaching were expressed in pore volume (PV) and were calculated separately for each water quality. During leaching process, EC in dS m^{-1} was measured periodically in percolated water (in 200 cm^3 water collected regularly from each soil column). The equivalent time for which each 200 cm^3 collected was recorded and involved in leaching curve construction.

Table (1): Some physical and chemical properties of soil and waters used in this study.

Soil						
Texture	**Sand, %**	**Silt, %**	**Clay, %**	**Bulk density, kg m^{-3}**	**Field capacity, %**	**Electrical conductivity, dS m^{-1}**
Sandy	93.4	4.2	2.4	1630	11.2	0.95

Water			
	Nile Water	**Salam Canal Water**	**Diluted Sea Water**
Electrical conductivity, dS m^{-1}	0.4	0.8	7.4
pH	8.01	7.27	7.67

For evaluation leaching requirement using Oster's model in comparison to leaching curve technique all initial EC values for used waters and all final EC values of irrigated soils were used in calculation processes. ET value involved in Oster calculation was chosen as the maximum water requirement over all treatments as found by Hokam and Azeem (2012), while WR values were chosen as the actual water requirement for each treatment individually.

RESULTS

For the total growing period, barley crop yield was affected by water deficit as represented using the values of crop response factors listed in Table 2.

Generally, the decrease in yield is proportionally less with the increase in water deficit (K_y ranged from 0.0 to 1.58) when crop irrigated with Salam water than that irrigated with Nile or diluted Sea waters. Therefore, the crops irrigated with Nile or diluted Sea water (i.e. with higher values of K_y) will suffer a greater yield loss than the crop irrigated with Salam water (i.e. with lower K_y value). Data in Table 2 showed that the lowest K_y values were found under the treatments of Salam Canal water. These mean that the crop irrigated with such water quality will be less affected by the inappropriate conditions of salinity or water shortage particularly under D_1 and D_2 levels with both PSB strains. As the results indicated the crop response factor (K_y) provide only the effect of water stress in a quality form and not quantity, where it qualitative the response of yield to water supply and explain the sensitivity or change occurred in the relative yield responded to the lack of soil water. So, a simple empirical model has been developed here to use for quantitative prediction of relative crop yield responded to water salinity interacted with soil moisture depletion.

Description of Yield Prediction Model

According to previous results obtained by Hokam and Azeem (2012), when the quality of used water changed from Nile water to diluted Sea water, the amounts of consumed water have been reduced, consequently, reduction of grain yield. Likewise this trend of effect was found also under each depletion level, where, consumed water was reduced when depletion levels changed from D_1 to D_3. So, water qualities affected the consumed water amounts and grain yields in a specific manner similar to the effect of moisture depletion levels. Therefore, the relationship between grain yield and consumed water was studied using simple correlation analysis to predict the responsibility of grain yield to each irrigation amount. One regression equation was achieved either for water qualities or depletion levels. The correlation analysis revealed that high positive correlation existed between grain yield and consumed water was presented by the second-order polynomial equations, Table 3. Regarding to the highest accuracy all equations provided R^2 values of 1. To describe the effect of irrigation water Salinity and water stress caused by depletion level in soil before irrigation on crop yield, a mathematical relationship was suggested here to explain how the crop yield responded to different water salinities and moisture depletion levels.

Table (2): Values of water response factor, K_y, calculated using equation 3.

Water Quality	Crop Response Factor, K_y					
	I_1			I_2		
	D_1	D_2	D_3	D_1	D_2	D_3
Nile Water N	-	2.56	1.94	-	2.00	2.24
Salam Canal Water S	0.00	1.00	1.5	0.46	1.13	1.58
Diluted Sea Water C	2.12	1.78	1.59	2.28	1.86	1.87

Table (3): Second order-polynomial equations for all treatments (average grain yield for both PSB strains was involved in calculations). The grain yield and water consumption were represented by Y and X, respectively.

Treatment	Water salinity effect	Treatment	Moisture depletion effect
	Polynomial eq.		Polynomial eq.
N x D levels	$y = -8E\text{-}08x^2 + 0.0031x - 7.8711$	**D_1 x water salinities**	$y = -4E\text{-}06x^2 + 0.0419x - 96.835$
S x D levels	$y = 2E\text{-}08x^2 + 0.0027x - 6.3558$	**D_2 x water salinities**	$y = -6E\text{-}06x^2 + 0.0456x - 88.631$
C x D levels	$y = -3E\text{-}07x^2 + 0.0032x - 5.7137$	**D_3 x water salinities**	$y = -8E\text{-}06x^2 + 0.0548x - 87.683$

So, it was necessary to develop some specific terms, such as Salinity ratio, R_s, to express the ratio between the salinity of used water, S_u, to the threshold value of salinity, S_{th}, after which the obtained yield is strongly decreased. The salinity values for the used waters, S_u, were 0.4 dS m^{-1}, 0.8 dS m^{-1} and 7.4 dS m^{-1}, for Nile, Salam and diluted Sea water, respectively. This salinity ratio should be inversely proportional to obtained crop yield, consequently to relative yield, Y_r, equation 5. Based on the previous study of Hokam and Azeem (2012) in which 3 dS m^{-1} was found as the threshold value, the values of salinity ratio for Nile water will equal to 0.13 (0.4 dS m^{-1} / 3 dS m^{-1}). Data listed in Table 4 showed that obtain grain yield was decreased as depletion level increased from D_1 to D_3, therefore, relative yield was inversely proportional to depletion level, equation 5. When both variables R_s and D are combined together in equation 7, the prediction factor C could be experimental estimated. Substituting one value of R_s for a particularly water quality and one depletion level with the corresponding value of the relative yield, Y_r, in equation 8, the value of constant C could be obtained and recommended to use for predict the expected relative yield. Applying data of grain yield, salinity of used waters and depletion level obtained by Hokam and Azeem (2012), the estimated values of prediction factor (i.e. constant C) in average, were equaled to 0.04, 0.09 and 0.37 for Nile, Salam and diluted Sea water, respectively.

Soil Salinization

The obtained results showed that salts were accumulated in all treated soils at the end of growing season at different concentrations, Table 5. This occurrence of accumulated salt may be resulted because of irrigation water was applied at limited amounts to keep each pot (for each particular depletion level) only at soil field capacity, therefore, there was no excess water to be drain and leach soil. The listed data showed that increasing depletion level had no effect on salt accumulation and the most affected soil with salt accumulation was that irrigated with diluted sea water. Under each water quality D_1-treatment had the highest salt concentration, this finding may be resulted because the D_1-treatments were the most treatments led to the highest water consumption.

Analysis of variance (ANOVA) and least significant difference (LSD) were done at a 0.05 significance level using the Costat software, version 6.311 (Steel and Torrie, 1980), Table 5. The results showed that, there are significant differences either between water qualities or moisture depletion levels, expressed as main effects. The results also emphasized that different treatments caused several significant responses of soil to residual salinity. In other word, interaction between water quality and moisture depletion had high significant influence on soil salinity. Table 5 showed that the effect of water quality and moisture depletion interaction on soil salinity can be ranked according to their significance as following: $CD_1 > CD_2 > CD_3 > SD_1 \approx SD_2 > SD_3 > ND_1 \approx ND_2 \approx ND_3$. Data described in Table 5 shown that the salt concentration in soils remaining at the end of the season has increased in soils irrigated with diluted sea water, which equivalent of three times that in the soil irrigated with Salam-Canal water, and eight times that remains in the soil irrigated with Nile water.

Soil Leaching Requirements

Previous data (Table 5) showed that all irrigated soil have been affected by the rationally irrigation practices, so that, salt accumulated in soil irrigated with Nile water reached 3.3 dS m^{-1}, while reached 27.1 dS m^{-1} for soils irrigated with diluted Sea water, therefore, salt leaching is necessary to maintain soil productivity. Leaching requirements have been calculated using the equation given by Oster (1994), results of leaching curves for soil columns (expressed in PV) and Hoffman's equation, where the corresponded soil salt concentrations were identified for all methods. Also the values of salt concentrations calculated using Hoffman's equation has been compared to those obtained by the experiment of soil leaching curve, in which used water amounts were calculated as soil pore volume, Table 6. ET value involved in Oster's model was chosen as the maximum water requirement over all treatments (5355 m^3 ha^{-1}) as found by Hokam and Azeem (2012), while WR values were chosen as the actual water requirement for each treatment individually, Table 4.

Table (4): Average grain yield involved in suggested model and experimental water requirements (Hokam and Azeem, 2012)

Water Quality		Average grain yield in Ton ha^{-1}.		
		D_1	D_2	D_3
N		6.4	4.4	2.2
S		6.7	5.2	2.9
C		3.1	2.3	1.5
Experimental water requirements, m^3 ha^{-1}, for different treatments				
		D_1	D_2	D_3
Water Quality	N	5355	4495	3600
	S	4665	4145	3340
	C	3990	3390	2895

Table (5): Residual soil salinity represented by soil electrical conductivity determined after crop harvest in response to different water qualities and different depletion levels: initial soil-EC was 0.9 dS m^{-1}

Used irrigation waters	EC, dS m^{-1}, of used waters	EC of irrigated soils after crop harvest under depletion levels			Average soil EC, dS m^{-1}.
		D_1	D_2	D_3	
Nile water	0.4	3.7	3.17	3.1	3.3
Salam Canal water	0.8	9	8.7	7.39	8.4
Diluted Sea water	7.4	29.5	26.9	25.03	27.1
Average Soil, EC		14.1	12.9	11.84	

LSD 0.05
Water quality = 1.21
Moisture depletion = 0.63
Water quality x Moisture depletion = 1.21

Table (6): Soil salinity, EC_S*, and leaching requirements, LR, using Hoffman and Oster equations, both calibrated experimentally with leaching curve.

Used waters	EC of used waters	Calculation based on Hoffman equation			Usage 1 PV in leaching experiment		Calculation based on Oster's equation	
		LR, %	EC_S in equation	EC_S Exp.	LR, %	EC_S Exp.	LR, %	EC_S Exp.
N	0.4	79	0.4	0.56	37	0.7	23	1.1
S	0.8	111	0.8	1.6	43	2.1	35	2.5
C	7.4	44	7.4	7.9	50	8.0	59	8.0

* All units of EC values are in dS m^{-1}.

Table 6 showed a comparison between the calculated water amounts for leaching requirements expressed as a percentage of the maximum applied irrigation water, as well as actual and calculated soil salt concentration using two different methods: Hoffman (1980) and that introduced by Oster (1994). Using Fig. 1 to 3 one threshold value could be used to represent a major leaching amount for the different water qualities and expressed as P V value. This threshold value is the minimum water amount passed through soil profile and reduced its salinity to an observed low level in comparison to its salinity before. Therefore, 0.5 P V could be taken as threshold value for all water qualities. This threshold value can reduce the salt concentration in the drainage water for leached soils from 16.5 to 1.3, from 70 to 4 and from 160 to 10 dS m^{-1} for Nile water, Salam-Canal water and diluted Sea water, as shown in Fig. 1, 2 and 3, respectively.

The obtained results from leaching experiment for soil columns based on pore volume theory compared with that calculated using Hoffman's equation showed that leaching with 0.9 pore volume of diluted Sea water reduced soil salinity to 8 dS m^{-1} instead of 7.4 dS m^{-1}. Leaching with 2.1 pore volume reduced soil salinity to 0.56 dS m^{-1} instead of 0.4 dS m^{-1}, and leaching with 2.6 pore volume reduced soil salinity to 1.6 dS m^{-1} instead of 0.8 dS m^{-1} for both Nile and Salam-Canal waters, respectively.

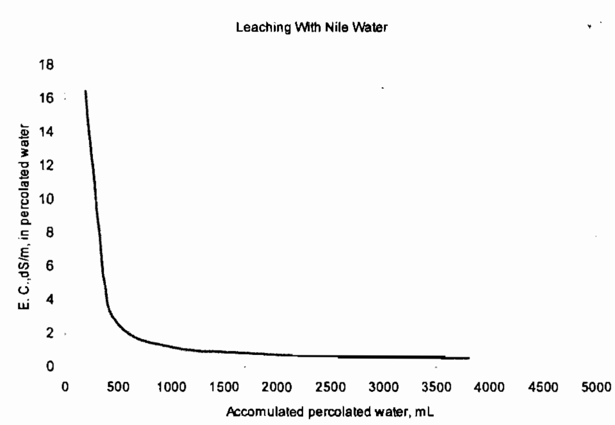

Figure (1): Leaching with Nile water, where soil EC after leaching reached 0.63 dS m^{-1} using soil pore volume, PV of 2.1.

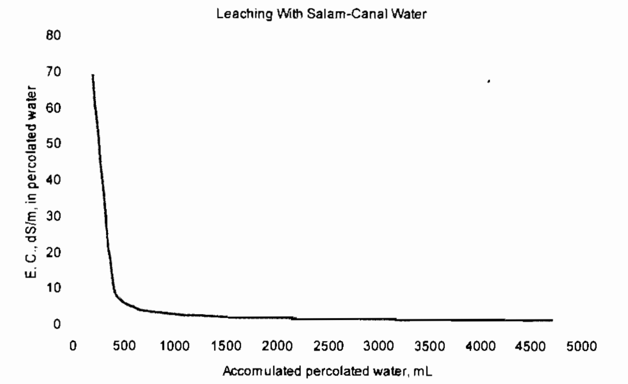

Figure (2): Leaching with Salam-Canal water, where soil EC after leaching reached 1.25 dS m^{-1} using soil pore volume, PV of 2.6.

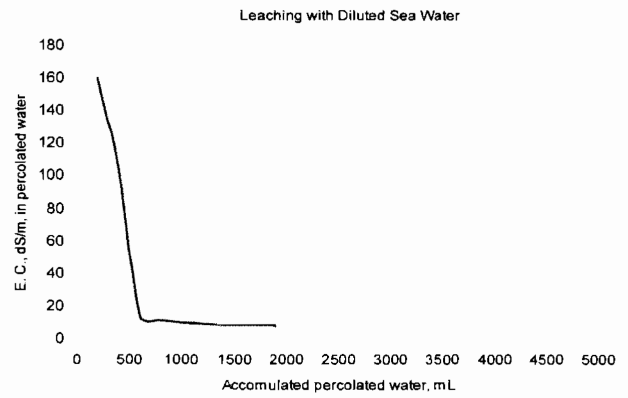

Figure (3): Leaching with Diluted Sea water, where soil EC after leaching reached 4.7 dS m^{-1} using soil pore volume, PV of 0.9.

The results showed that the leaching process based on Hoffman's equation can be used reliable particularly at less saline water, but it requests a prior knowledge of the salt concentration values will be present in the soil at the end of season to be involved into the equation and this is difficult to predict. Therefore, the LR values obtained using Oster's equation (i.e. equation 12) were calculated simpler using some water requirements data. Values of LR for all treatments were calculated using equation 12. The results showed that all treatments will need to be leached except ND_1 where irrigation water applied was equaled to the maximum evapotranspiration. Generally, water amounts needed for leaching were increased as depletion level or water salinity increased, where the highest amount was found for CD_3 treatment. It is unrealistic to apply more than 100% of irrigation water as found with Salam water, as shown in Table 6.

DISCUSSION

Crop Response Factor

Among eighteen treatments represented the interaction between three salinity levels, three depletion levels and two PSB strains studied by Hokam and Azeem (2012), usage of Salam-canal water with depletion level equals to 25 % of soil field capacity was found and recommended to be the optimum irrigation practice under such study conditions. Their results showed that soil moisture depletion resulting in water stress on the plant, and have negative effect on crop evapotranspiration and crop yield. Water stress in the plant can be quantified by the rate of actual evapotranspiration (ET_a) in relation to the rate of maximum evapotranspiration (ET_m). So, in D_1-Nile water treatment, the crop water requirement, CWR, was fully met from the available water, then $ET_a = ET_m$ (i.e. when available soil water to the crop is adequate). On the other hand, under D_2 and D_3 treatments, where the full CWR was not met, $ET_a < ET_m$ (i. e. when available soil water is limited). The ratio between ET_a and ET_m is named relative evapotranspiration (ET_r). In a same manner relative yield, $Y_r = Y_a / Y_m$, where Y_a is the actual yield, Y_m is the maximum yield and $Y_a = Y_m$ when full water requirements are met. The model mostly used is the one proposed by Stewart et al. (1977), it is an empirically factor, called yield response factor, K_y, (derived from Y_r to ET_r) and links the relative yield decrease with relative evapotranspiration deficit due to effect of water stress and could be quantified using equation 3.

There is a great agreement between the assessments of K_y values and what found by Hokam and Azeem (2012) from the viewpoint of the water use efficiency, where the D_1 and D_2 were the most recommended treatments. It is unfortunate that this approach of yield response factor, K_y, qualitative the response of yield to water supply and explain the sensitivity or change occurred in the relative yield responded to the lack of soil water. It does not quantity the decrease in yield responded to the deficit in crop evapotranspiration. For that failure we offer the next model that may predict how many the relative yields could be obtained under specific values of water salinity and moisture depletion. The obtained results showed that the value of constant C that presented the prediction factor is increased as the salinity level increased. Fig. 4 illustrates the relationship between constant C and the corresponding water salinities.

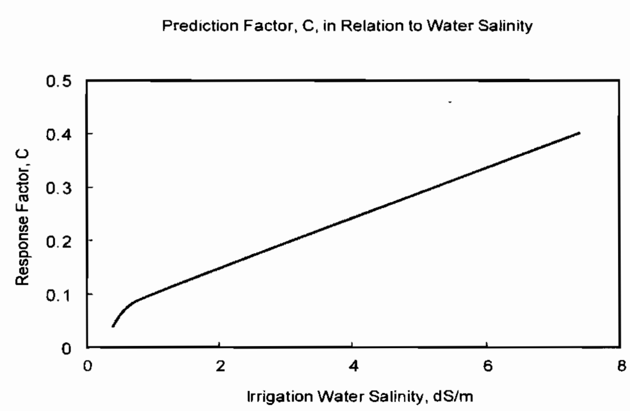

Figure (4): The relationship between the prediction factor, C, and salinity of used water

Yield response factor is selected to evaluate the relative yield decrease as related to the relative evapotranspiration deficit, Doorenbos et al. (1986). This is clear from this mathematical relationship that more decrease in the value of the crop response factor indicates that the obtained yield will be less affected as a result of the accident reduction in water consumption under certain circumstances. Application of equation 8 indicated that the best value for the coefficient of response and thus indicate that the best conditions (i.e. favorable treatment to be recommended) for the highest production yield is when the value of this parameter closed to zero, while the treatment will be not recommended as the value increased positively for zero.

As mentioned above, the low values of crop response factor, K_y, indicates that the obtained yield will be less affected as a result of the accident reduction in water consumption under certain circumstances. Therefore, the best value for the coefficient of response, subsequently, the most favorable treatment to be recommended is when K_y value, is minimized to 0, while it is not recommended when that one value is increased positively for zero. Results listed in Table 2 showed that the lowest K_y values were found under the treatments of Salam Canal water. These results mean that the crop irrigated with such water quality will be less affected by the inappropriate conditions of salinity or water shortage particularly under D_1 and D_2 levels. The results showed that there is good agreement between the model values and the actual values confides strengthen in the validity of the empirical equation developed to predict relative crop yield based on the certain relative salinity factor and depletion level.

Soil Salinization

Generally, under saline irrigation water and low soil moisture content, the concentration of soil solution become high and this makes it difficult for crop to absorb moisture and nutrients, therefore, results in crop damage. As the irrigation waters have been rationally applied, soil salinization was expected particularly under irrigation with saline water. So, the second objective was to study how soil salinity could be reduced to prevent salinity hazard, and at the same time irrigation water amounts could be saved using a defined method. Result of soil salinization occurred after crop harvest was stupendous, where the salt concentration has increased in soil treatments which exposed to less moisture depletion compared to those exposed to severe moisture depletion, Table 5. This result may explain that the treatments exposed to less depletion had received high amounts of water consumed by developing crop over the growing season as evidenced by the results of water consumption obtained by Hokam and Azeem (2012). This finding may result in increasing the amount of salts reaching the soil. This trend of results has been appeared under all types of water used.

For validation of both calculated LR methods a leaching curve experiment has been achieved on soil columns after all treatments. Leaching curves shown in Fig. 1 to 3 indicated that leaching water amounts were strongly affected by soil salinity and salt concentration of used irrigation waters. Leaching water amounts have been calculated based on pore volume expression and equaled to 0.9, 2.1 and 2.6 P V for diluted Sea water, Nile water and Salam-Canal water, respectively. Different treated soils were leached with the same water quality used for irrigation during the season. The amounts of water used for leaching were expressed in pore volume based on equation 8 (Hoffman, 1980). Soil pore volume (P V) was found to be 1700 cm^3, and for saturated soil the calculated water amounts as pore volume was 2.1, 2.6 and 0.9 P V, for Nile water, Salam Canal water and diluted Sea water, respectively. Leaching curve was constructed for each soil to monitoring the progression of leaching process, Fig. 1 to 3. The Figures explain changing of percolated water salinity (EC in dS m^{-1}) in the accumulative percolation water, in mL. Data showed that, for all treatments after leaching with 1.0 P V salt concentration was reduced to 7.9, 2.1 and 0.70 dS m^{-1} for diluted Sea water, Salam-Canal water and Nile water, respectively. It is advisable to leach the soil irrigated with diluted Sea water one time with Nile water or Salam-Canal water and following each growing season.

Results indicated that the salt concentration, which will remain in the soil when the quantities of leaching water applied based on Oster's equation will reach nearly double those actually remaining under water added according to the method of Hoffmann. At the same time this remaining salt concentration is still relative low and safe for many crops. Although salt concentrations calculably expected based on Oster's equation are highly relative to that using Hoffman, the amounts of water applied based on Oster (especially under the Nile and Salam canal waters) are reduced to about one-third of that calculated according to Hoffman and led to the provision of large amounts of water available for irrigation. For example, the leaching experiment showed that under irrigation with Nile water, the LR value reached 79 % with Hoffman and reduced soil salinity to 0.56 dS m^{-1}, while reached 23 % according to Oster and reduced soil salinity to 1.1 dS m^{-1}. It is noted from the results that there is no difference when using either method for both salt concentration remaining in soil or the amount of water used in leaching and that at the level of salinity close to the concentration of diluted Sea water.

CONCLUSION

According to the comparison between crop response factor, Ky, model and the suggested model for grain yield prediction, the results showed that the suggested can be helpful to obtain a quantitative prediction of relative yield, while the crop response factor can only give qualitative prediction. According to crop response factor the results showed that the lowest Ky values were found under the treatments of Salam Canal water. These mean that the crop irrigated with such water quality will be less affected by the inappropriate conditions of salinity or water shortage particularly under D1 and D2 levels with both PSB strains. Also, the results showed that there is a good agreement between the values of suggested model and the actual values confides strengthen in the validity of the empirical equation developed to predict relative crop yield of barley cultivated in sandy soil under a certain salinity and depletion levels. Although salt concentrations calculably expected based on Oster's equation are highly relative to that using Hoffman's equation, the amounts of water applied based on Oster (especially under the Nile and Salam canal waters) are reduced to about one-third of that calculated according to Hoffman and led to the provision of large amounts of water available for irrigation. Since all plants do not respond to salinity in a similar manner, where some crops can produce acceptable yield at much higher soil salinity levels than other, so, the yield response prediction model may be limited to barley crop, and need to be tested and validated in more extensive field experimentation with various levels of water salinity.

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طرق بسيطة للتقدير الكمي لإنتاج المحصول وإستجابة التربة وذلك لنوعيات مختلفة من المياه والإستنزاف الرطوبي

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هذه الدراسة هي محاولة للتقدير الكمي لتأثير تداخل إختلاف نوعيات مختلفة من مياه الري مع مستويات مختلفة من الإستنزاف الرطوبي بالتربة, وذلك علي إنتاج المحصول والإحتياجات الغسيلية للتربة المتأثرة بالأملاح. وقد تم زراعة محصول الشعير في التربة الرملية كتجربة أصص في حقل مفتوح بالإسماعيلية مصر. تم تجميع ثلاث نوعيات من مياه الري وذلك من ثلاث موارد مختلفة هي ١) مياه النيل تركيزها الملحي ٠,٤ ديسيسيمنز/م، 2) مياه ترعة السلام تركيزها الملحي ٠,٨ ديسيسيمنز/م، ٣) ماء بحر مخفف وتركيزه الملحي ٧,٤ ديسيسيمنز/م. هذا وقد تم ري محصول الشعير الشتوي بالثلاث نوعيات مختلفة من المياه حيث تم إضافة كل نوع من المياه تحت ثلاثة مستويات مختلفة من الإستنزاف الرطوبي: ٢٥٪، ٥٠٪ و٧٥٪ من السعة الحقلية للتربة المدروسة. وقد تم إستنباط نموذج تجريبي للتنبؤ بإنتاج المحصول وتقييمه بالمقارنة ببعض النماذج الشائعة مثل نماذج Stewart وMass-Hoffman. وأظهرت النتائج أن النموذج المقترح يمكن أن يستخدم بنهج موثوق فيه وذلك للتنبؤ بالإنتاج النسبي لمحصول الشعير المنزرع في التربة الرملية المروية بمياه مختلفة الملوحة تحت مستويات مختلفة من الإستنزاف الرطوبي بالتربة. فضلاً عن ذلك فإنه يمكن تحديد أفضل الطرق لحساب الإحتياجات الغسيلية للتربة المتأثرة بالأملاح نتيجة الري بمياه مالحة. وقد تم اختبار صحة نموذج Hoffman الشائع الإستخدام وكذلك نموذج Oster لحساب الإحتياجات الغسيلية وذلك إستناداً إلى تجربة منحنى الغسيل. كما أشارت النتائج إلى أن النموذج المستنبط هنا للتنبؤ بالإنتاج النسبي لمحصول الشعير يعتبر دالة لكل من ملوحة مياه الري وكذلك مستوي الإستنزاف الرطوبي بالتربة. وإستناداً إلى البيانات الناتجة من تجربة منحني الغسيل فقد وجد أن هناك زيادة في قيم الإحتياجات الغسيلية المحسوبة بمعادلة Hoffman وذلك مقارنة بما هو محسوب بمعادلة Oster. إن مقدار كمية المياه المحسوبة بإستخدام معادلة Oster يمكن أن تنخفض إلي ثلث تلك الكمية المحسوبة بمعادلة Hoffman مما يؤدي إلي توفير كميات كبيرة من المياه تصبح متاحة للري.